IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

ATTY.'S DOCKET: YESHURUN=3A

In re Application of:)
Yehoshua YESHURUN et al)
Appln. No.: 09/904,585)
Filed: July 16, 2001)
For: LIGHTWEIGHT ARMOR AGAINST FIREARM PROJECTILES)

Art Unit: 1771
Examiner: U. RUDDOCK
Washington, D.C.
Confirmation No. 3898
November 24, 2005

DECLARATION UNDER 37 CFR §1.132

I, Yehoshua Yeshurun of 17 Avshalom Street, Haifa, Israel, declare that:

I am a senior scientist at the Ballistic Center in Rafael Ltd. (Armament Development Authority). My academic record includes the following degrees:

- B.Sc. in Mechanical and Materials Engineering from Ben-Gurion University, Israel, (1979);
- M.Sc. in Materials Engineering from Technion Israel Institute of Technology, Israel, (1983);
- D.Sc. from the Department of Materials Engineering at the Technion Israel Institute of Technology, Israel, (1988).

I am one of the inventors of the invention disclosed in US patent application no. 09/904,585 (hereinafter "the application").

Regarding the stated reference of Fischer et al, it is my opinion that a person skilled in the art of armor manufacture would understand that a "first ply, which is disposed in the direction of an expected impact" refers to a ply facing the expected impact, i.e. in a laminate consisting of a plurality of plies the ply "disposed in the direction of an expected impact" is the ply first impacted by an oncoming projectile.

Fischer consistently uses the word "dispose" in this manner, for example:

- "adhesive layer disposed there between" (col. 1, line 16)
- second ply, which is disposed behind the first ply" (col. 1, line 65)
- third ply, which is disposed behind the second ply" (col. 2, line 1)
- forth ply, which is disposed behind the third ply" (col. 2, line 52)
- fifth ply, which is disposed behind the fourth ply" (col. 2, line 54)

Furthermore, Fischer must teach which ply faces the expected impact as it states in the reference: "The results show that the order of the laminate's successive plies is important in achieving good ballistics performance" (col. 13, line 4) and that the "respective first, third and fifth plies have a uniform thickness in a proportion of about 2:4:1" (col. 13, lines 48-50 and col. 14, lines 65-67). As the thickness of the first, third and fifth plies differ, the reference, according to Fischer's aforementioned statement regarding "order", must specify which ply faces

the expected impact else a person skilled in the art would be lacking the information as to in which orientation to install the laminate. Therefore, Fischer teaches the "first ply, which is disposed in the direction of an expected impact" to specify which ply faces the expected impact.

The remainder of the reference further supports this understanding of the phrase "disposed in the direction". This is seen from the experimental examples given and accompanying test result criteria. In the examples given for the laminate's ballistic response, the experiments were performed under standard test conditions "specified in the Underwriters' Laboratories Class II method" (Col. 5, lines 47-49) and "Class III method" (Col. 10, lines 24,25). These standard tests are normally performed with the armor disposed perpendicular to projectile line of flight unless specifically indicated otherwise, which is not seen to be the case in Fischer.

Furthermore, it is clear that a person skilled in the art could not understand Fischer to be teaching a first ply of PMMA in an orientation different to that of the subsequent plies. This is because the reference consistently teaches the invention as one integral piece, for example:

- "Impact resistant laminate" (Patent title, first line of abstract). The word laminate is understood to mean an integral structure with parallel plies.
- "The laminate has a substantially better ballistic response" (col. 2, line 12). The word laminate is found consistently and repeatedly throughout the specification.

- each ply is "immediately behind" (e.g. col. 13, line 34) the preceding ply, further teaching a integral structure.

- every figure in the reference supports the view that Fischer teaches an integral structure with parallel plies.

Therefore, according to the possible understanding that the first ply is inclined or slanted, by the words "disposed in the direction of an expected impact", it would necessarily follow that the entire laminate is inclined or slanted. The difficulty raised with this understanding of Fischer being that if the entire laminate is slanted or inclined and each ply is parallel and integral to each other then it makes no sense for Fischer to specify only one ply as being slanted or inclined, and not to specify the entire laminate. Therefore the only logical understanding of "disposed in the direction of an expected impact" is that Fischer is teaching that the first ply is the ply facing the expected impact.

In summary of the above argument, Fischer does not teach a slanted or inclined first ply. Furthermore, a person skilled in the art would not learn from Fischer that the use of a PMMA ply, in isolation of the combination of plies taught in the reference, provides a ballistic response that is unexpectedly high, as will be explained below.

Fischer consistently teaches the use of a laminated armor configuration which requires the first ply of PMMA in conjunction with other plies consisting of different

materials in an order specified in the reference. This is indicated by the following statements:

- "in accordance with the invention, the laminate includes at least three transparent plies" (col. 1, line 59)
- "The three plies cooperate to provide a ballistic response that is unexpectedly high" (col. 3, line 22)
- "the laminate has a substantially better ballistic response than any one of the three materials by itself.." (col. 2, line 10)
- "The results show that the order of the laminate's successive plies is important in achieving good ballistics performance." (col. 13, line 4)

Therefore, a person skilled in the art would learn from Fischer that only by using a PMMA ply with the combination of plies taught in the reference would provide a ballistic response that is unexpectedly high.

The stated need for the combination of plies in Fischer demonstrated that the advantageous properties of a PMMA layer alone had not been realized.

Furthermore a skilled person could not learn from Fischer an armor configuration for the prevention of penetration from a high threat level projectile, such as an armor piercing (AP) projectile. In all of the examples given in Fischer only low threat level projectile types are specified, such as:

- "soft point projectile" (col. 5, line 45)
- "lead point" (col. 7, line 26; col. 10, line 16)
- "fragment-simulated projectile (FSP)" (col. 8, line 13; col. 11, line 65; col. 12, line 59)

During our experiments on various brittle materials it was found that when epoxy resin and PMMA are impacted by an armor piercing (AP) projectile, they may act on the projectile in a manner different from other tested brittle materials. Namely, the experiments showed that under certain conditions, inclined targets with epoxy resin or PMMA material at their front, surprisingly caused the projectile to ricochet from the target after having been yawed thereby (i.e. rotated within the material), whereby the projectile's penetration through the material was prevented. Such a possibility is mentioned in the application (see pages 222, final paragraph continuing onto next page). Consequently, PMMA and epoxy resin appear to be capable of providing better ballistic performance than other brittle materials, notwithstanding the fact that they are of lower density and hardness then other substances we have experimented with.

Computer simulations showed the same results and these simulations and their comparison to experimental results are summarized in an article named "Ricochet of 0.3" AP projectile from inclined polymeric plates", a copy of which is enclosed herewith as annex A.

The experiments and simulations show that for the desired effect of maximizing the asymmetric interaction between an armor layer and the projectile, the slanted layer must have high dynamic compressive strength, high brittleness and low density (page 224, final paragraph). Therefore PMMA and epoxy resin are currently the most suitable materials for utilizing as a slanted armor layer.

In addition, tests were performed on PMMA plates of different thicknesses, slanted at different angles. During the test a projectile was fired, in this case a 7.62x39 API BZ (AK47, armor piercing) bullet with an impact velocity of 720m/s, at a PMMA plate.

It was found that the best result was produced when the PMMA layer was oriented at an angle of obliquity of 60 degrees to the projectile line of flight. In that case a plate thickness of about 20mm was sufficient to prevent the projectile from penetrating through the plate. Whereas, firing the same projectile under the same conditions at a PMMA plate that was oriented perpendicular to the projectile line of flight, a plate thickness of not less than about 110mm was necessary to prevent the projectile from penetrating through the plate.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements are made with knowledge that willful false statements and the like are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code, and that willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Date: November 22, 2005

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Ricochet of 0.3″ AP projectile from inclined polymeric plates

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Abstract

When a rigid armor piercing (AP) projectile impacts an inclined plate it can be deflected by the asymmetric forces, which the target exerts on the projectile. This is a well-known phenomenon which has been investigated by several workers impacting various metallic targets with AP projectiles. These works have shown that if the incidence angle is small enough the projectile can ricochet from any metallic target, provided the target is thick enough. In the present study we investigated the deflection, and ricochet, of 0.3″ AP projectiles impacting inclined polymeric targets, which, to our best knowledge, were not investigated before. We concentrate our attention on Plexiglas targets, which turned out to exert the strongest asymmetric forces on the AP projectile. We present a thorough 3D numerical study following the important properties of the target, which control the ricochet and deflection processes. It turns out that these properties are the high compressive strength and the low tensile strength of the target. In other words, the high brittleness of Plexiglas is responsible for the large deflection which was observed in our experiments. Other polymers, less brittle, resulted in a much lower effect or no effect at all.

Keywords: Ricochet; Armor piercing projectiles; Plexiglas; Brittle failure

1. Introduction

The interaction of kinetic energy projectiles with an inclined plate is characterized by asymmetric forces, which are exerted by the plate, deflecting the projectile from its initial line of attack. This asymmetry takes place during the early stages of penetration, until the projectile's nose is fully embedded in the target plate. Given the right combination of projectile velocity, target strength and angle of attack, these asymmetric forces can result in a ricochet of the projectile, preventing perforation of the target. Goldsmith [1] reviewed much of the literature concerning inclined plate impact, including the analytical model of Tate [2] for rigid long rod

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ANNEX A

ricochet. In recent works on long rods [3,4] the bending of the nose was taken into account, in order to simulate a more realistic situation for these interactions. The most extensive work on this subject is by Recht and Ipson [5] who analyzed the various parameters involved in the interaction of armor piercing (AP) projectiles with inclined metallic plates. They outlined a configurational map which gives the outcome of this interaction in terms of deflection, ricochet and shattering of the projectile as a function of obliquity and impact velocity. Most of the work which has been done on this subject is concerned with strong metallic plates, in order to achieve ricochet at maximum efficiency (minimum target weight and high obliquity).

The work described here is concerned with 0.3″ AP projectiles impacting inclined polymeric targets. The aim of our work was to find whether these low-density materials could exert strong enough forces on the projectile in order to deflect its course of penetration. The materials we investigated included: Plexiglas, epoxy, PVC and polycarbonate. Of these, Plexiglas and epoxy (Epon 815) resulted in the strongest asymmetric forces, as evidenced by flash X-rays, following the course of the projectile. The strong effect of Plexiglas was discovered by Yeshurun et al. [6] and Yeshurun [7] about 5 years ago in an extensive study which included the above mentioned materials. In order to understand the important material parameters, which determine the asymmetric interaction, we performed a large series of three-dimensional (3D) simulations with the lagrangian processor of the Autodyn 3D code, which will be described here. We should emphasize that our aim was to understand the general features of the mechanism causing this strongly asymmetric interaction, rather than simulating the process in an accurate manner. It is a 3D process which by nature, is very complex to simulate. Thus, we did not wish to go into a detailed 3D numerical simulation work, involving complex material modeling. Rather, the simulations we performed illustrate some overall effects instead of quantitatively describing AP projectile impact on real Plexiglas plates.

2. Experiments

The experiments were performed in the Ballistics laboratory at RAFAEL, using several types of 0.3″ AP projectiles. The cores of these projectiles weigh 3.5–5.5 g and their muzzle velocities are in the range of 720–850 m/s. The targets were positioned some 7 m from the rifle, at various obliquities ranging from 20° to 50° (relative to the projectile line of flight). Their thickness ranged between 10 and 50 mm and their lateral dimensions were $250 \times 80\,mm^2$. Several 150 kV flash X-ray tubes were used to follow the deflection of the projectile from the moment of impact at consecutive time intervals of about 150 µs. Typical results with a 20 mm Plexiglas plate at an obliquity of 30° are shown in Fig. 1. One can clearly see the projectile emerging from the target with a large deflection from its original orientation. The most interesting feature in these experiments is the large angle between projectile axis and its line of flight, after it emerges from the target. This phenomenon is very different from what we are used to see with regular ricocheting of AP projectiles from metallic targets, where the projectile axis remains along its line of flight. Due to the brittleness of the Plexiglas target, a large area around the impact point (tens of centimeters) is highly cracked.

Another important point to note is that at an obliquity of 30°, metallic plates are often penetrated by these projectiles (if not shattered by the high strength of the target). In order to

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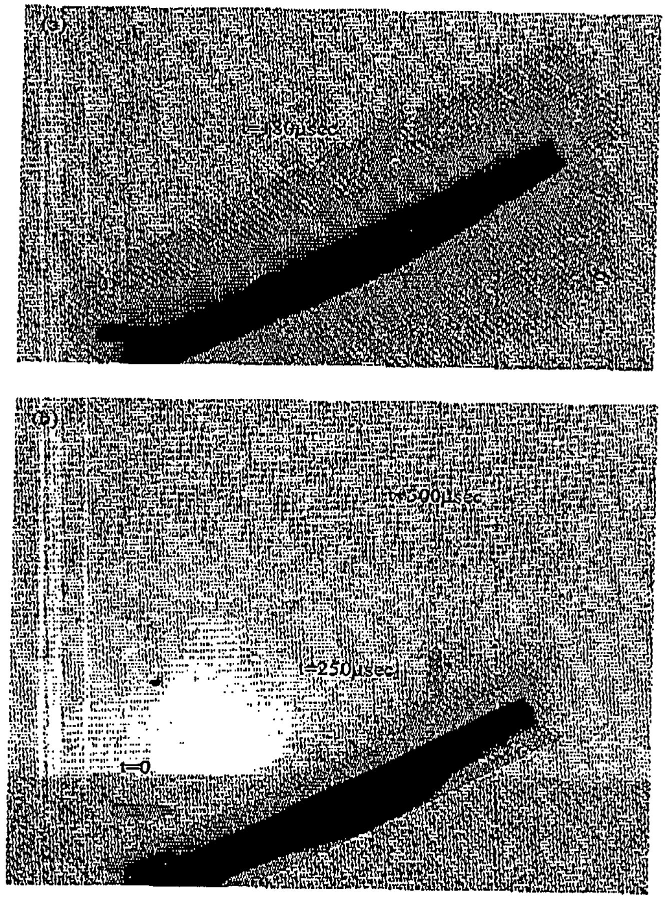


Fig. 1. Typical flash X-ray results of experiments with 20 mm Plexiglas plate at an obliquity of 30°.

achieve a ricochet from an aluminum plate a much more acute angle of obliquity is needed. Thus, we can clearly state that the Plexiglas plate is influencing the projectile via a new mechanism which we did not observe with metallic plate. The projectiles emerging from inclined Plexiglas targets are both extremely deflected and yawed. This mode of interaction was also observed with epoxy targets, while all the other polymers we tested did not result in such an effect. The epoxy we used is Epon 815 which was cast to plates with dimensions similar to those of the Plexiglas targets.

3. Numerical simulations

A series of numerical simulations, with the lagrangian processor of the Autodyn 3D code, was performed in order to gain some understanding for the physical processes which are responsible

for the strong effect observed with the Plexiglas targets. The steel projectiles were simulated with a simple von-Mises yield criterion ($Y_0 = 1.5$ GPa = const, with no strain hardening or strain rate effects) and the well known equation of state parameters for steel. The material parameters for the steel were $\rho_0 = 7.83$ g/cm^3, $c_0 = 4.58$ mm/μs, $G = 81.8$ GPa and $P_{min} = -3$ GPa. For the Plexiglas targets we used the common values for density, sound velocity and shear modulus ($\rho_0 = 1.18$ g/cm^3, $c_0 = 2.57$ mm/μs, $G = 2.3$ GPa). In different simulations we varied the mechanical properties of the Plexiglas plate in order to determine their influence on the ricochet phenomenon. In all our simulations the thickness of the target plate was 20 mm and impact obliquity was 30°. Also, unless otherwise specified, the impact velocity was 720 m/s (the muzzle velocity of the AK47AP rifle we used in the experiments). The targets in our simulations had 30 elements on their thickness (20 mm).

Our initial understanding was that there are three material properties which maximize the asymmetric interaction between Plexiglas and the projectile. These are: (1) high dynamic compressive strength, (2) high brittleness and (3) low density. In the following paragraphs we describe our simulation results, as obtained by changing the corresponding properties of the Plexiglas plate. These results demonstrate the importance of these three material properties for the ricochet phenomenon. We would like to stress again an important point concerning the overall aim of these simulations. Our main interest is in conducting a sensitivity study rather than finding a perfect match between simulation and experiment. Thus, we were looking for trends in the ricochet phenomenon and, particularly, the important material parameters which are responsible for this very strong effect. As we show later on, a close resemblance is obtained between simulation and experiment by using material properties which are common for Plexiglas. Thus, we did not find it necessary to use a comprehensive characterization of this material.

3.1. The effect of compressive and tensile strengths

Plexiglas is known to have a relatively high dynamic compressive strength. Plate impact experiments by Barker and Hollenbach [8] have shown that its Hugoniot elastic limit is about 0.7 GPa. This means that the dynamic compressive strength of this material is near 0.35 GPa which is also the value tabulated in codes like the Autodyn. This relatively high value of compressive strength is the result of the high strain rates which the Plexiglas experiences under dynamic loading conditions. The material is also known to be extremely brittle with a spall strength of 0.1–0.15 GPa (see [9,10] for example). Thus, one should assign a very low dynamic tensile strength for this material in the simulation. The appropriate material parameter which represents dynamic tensile failure in the code is P_{min}, the spall strength of the material.

The way these two parameters affect the ricochet process can be explained as follows: The high compressive strength is needed in order to exert a large asymmetric force on the nose of the projectile by the target during the first stages of penetration. This force will deflect its line of flight inside the target. The high brittleness is needed to ensure that the asymmetric forces will continue to act during later times. This is achieved by the fact that target material near the entrance hole fails by tension, due to release waves from the impact face. At the same time target material in the bulk is still intact, exerting the upward push continuously. This

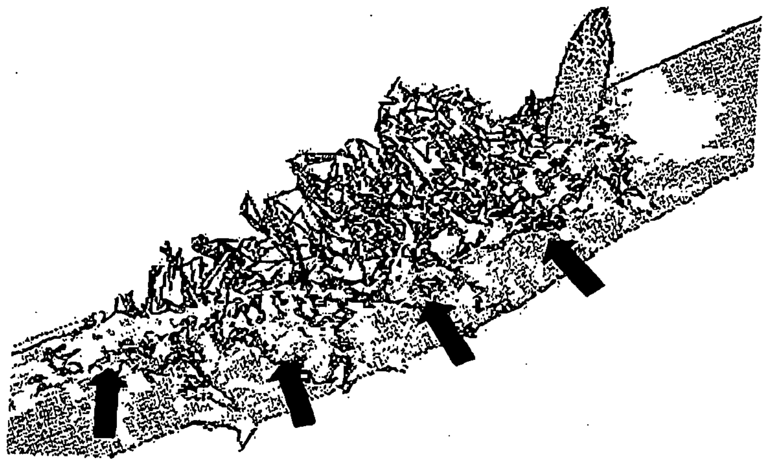
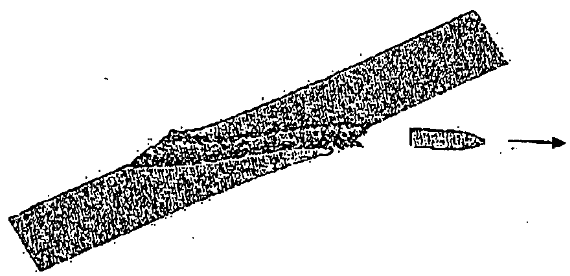
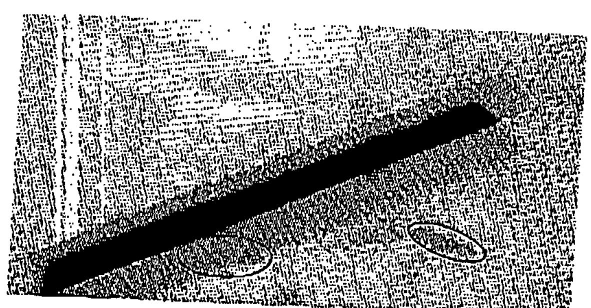


Fig. 2. The asymmetric force acting on the projectile during penetration of a brittle plate ($Y = 0.4$ GPa, $P_{min} = -0.02$ GPa).



(a)



(b)

Fig. 3. (a) The trajectory of the projectile in a ductile target with $P_{min} = -0.1$ GPa, and (b) experimental result with a ductile target (20 mm thick polycarbonate plate).

situation is very clear in Fig. 2 which is taken from one of the simulations to be described later on. Material elements which failed are white while intact elements are dark. It is clearly seen that the projectile is constantly experiencing an upward push by the intact material below its nose, as the arrows show. In this simulation we used $Y = 0.4\,\mathrm{GPa}$ and $P_{\min} = -0.02\,\mathrm{GPa}$ for the Plexiglas plate.

In order to strengthen this interpretation we performed a similar simulation with a much higher value for $P_{\min}$ ($=-0.1\,\mathrm{GPa}$, appropriate for a more ductile material) and a lower compressive strength ($Y = 0.1\,\mathrm{GPa}$). Fig. 3a shows that in this case the projectile perforates the target, performing the familiar S shaped perforation channel due to the similar asymmetric forces at the impact and back faces. Clearly, the material near the impact face does not fail so that the asymmetric nature of the forces is much smaller. Fig. 3b shows our experimental result with a 20 mm PC plate which was perforated by the projectile in a similar way.

Fig. 4 shows the penetration process in a simulation with $Y = 0.4\,\mathrm{GPa}$ and $P_{\min} = -0.005\,\mathrm{GPa}$ for the Plexiglas plate. One can clearly follow the deflection and yaw imparted to the projectile by this extremely brittle plate. This is the most extreme combination of Y and $P_{\min}$ we used in our simulations, representing the most brittle case. In fact, one can assign a brittleness figure of merit through the ratio of Y to $P_{\min}$ (the higher this ratio the more brittle is the material).

Fig. 5 shows a comparison between this simulation result and an actual experimental X-ray flash at 200 μs after impact. The orientation of the projectile is well reproduced in the simulation, as well as its position in the target. Thus, one can conclude that the values we chose for Y ($=0.4\,\mathrm{GPa}$) and $P_{\min}$ ($=-0.005\,\mathrm{GPa}$) represent the overall effect of the Plexiglas on the AP projectile. Moreover, the massive failure of the Plexiglas plate around the impact point in the simulation, as shown in Fig. 5a, is very similar to the extent of damage in our recovered targets. As stated above, large sections of the target are totally shattered and removed. The rest of the plates were found to be highly cracked in a very brittle way.

In order to demonstrate the relative importance of each one of these strength parameters we show in Fig. 6 the state of the projectile in simulations with varying compressive strength at a constant $P_{\min}$ (Fig. 6a) and with varying $P_{\min}$ at a constant compressive strength (Fig. 6b). In another simulation we increased the compressive strength of the target to 1.0 GPa and obtained a regular ricochet, as obtained with metallic targets (see Fig. 6c). Here the projectile is deflected before embedding into the target.

One can clearly see the strong sensitivity of the asymmetric action to these two material strength parameters. In particular, with a low value of Y ($=0.1\,\mathrm{GPa}$) the projectile perforates the target exiting with an orientation nearly parallel to the target faces. This value of compressive strength is, apparently, too low to prevent full perforation of the target. Still, the axis of the projectile is along a different direction than what is usually experienced with ductile targets, which deflect a rigid projectile towards the normal to the target faces (as in Fig. 3).

The influences of tensile and compressive strengths can be further demonstrated through the evolution of projectile deflection and yaw angles during the process of penetration (Fig. 7a and b, respectively). With increasing brittleness, the deflection and yaw of the projectile, as it exits from the plate, are higher. The deflection is the angle between the original direction of the projectile and its axis at a given time while the yaw is the angle between its axis and direction of flight at any instant.

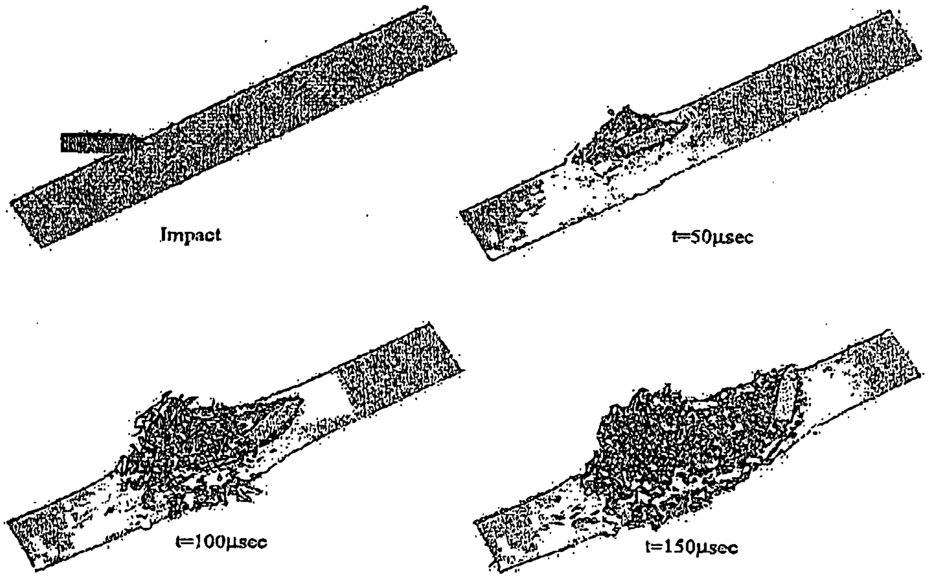
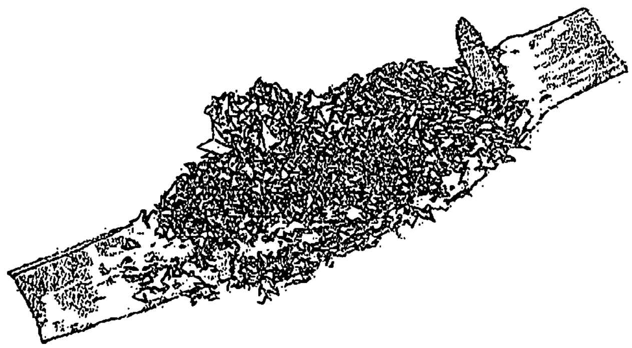


Fig. 4. Time evolution of projectile penetration into a very brittle Plexiglas plate ($Y = 0.4\,\text{GPa}$; $P_{\min} = -0.005\,\text{GPa}$).

3.2. *The influence of target density*

The next issue we investigated was the influence of plate density. This was done for strength values of $Y = 0.3\,\text{GPa}$ and $P_{\min} = -0.005\,\text{GPa}$, changing the density of the plate from 1.2 (Plexiglas) to 2.7 (aluminum-like) and $4.5\,\text{g/cm}^3$ (titanium-like). Fig. 8 shows the results of these simulations at $130\,\mu\text{s}$ after impact. Clearly with a higher density of the target, less failure is observed in the parts above the projectile, resulting in less deflection. We should note that these are only sterile simulations, in the sense that no aluminum or titanium plates can be made so brittle. Still, we see that the density of Plexiglas is low enough to amplify the deflection of the projectile. A possible explanation for the influence of target density can be obtained by considering the velocity imparted by the impact shock wave to the target elements. At a given impact velocity a lower target density will result in a lower shock amplitude but a higher material velocity in the target. Thus, the failed elements above the entrance hole will be removed more quickly for the lower density targets, exerting less force on the projectile. On the other hand, with higher target densities the amplitudes of the shock waves generated by the impact will be higher, so that more damage is expected in the target. This is clearly seen in Fig. 8 where more cells have failed in the bulk of the denser targets. Still, these cells remain at their position for longer times, as compared with the failed cells in the less dense targets.



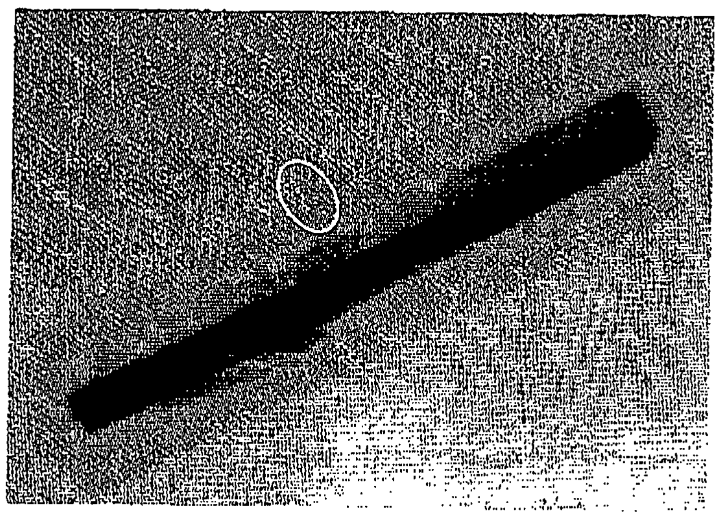


Fig. 5. Comparison between simulation and experiment (at 200 μs after impact).

3.3. *The influence of projectile velocity*

The simulations described above were performed with an impact velocity of 720 m/s which represents the muzzle velocity of AK47AP projectile. Our understanding is that a nondimensional parameter which should be relevant in this case (as in many of the terminal ballistics phenomena) is $\rho_p V^2/Y_t$ (ρ_p = projectile density, V = impact velocity and Y_t = target strength). In order to check this point we performed two extra simulations changing both V and Y in such manner that V^2/Y_t remains equal to a reference simulation with $V = 720$ m/s and $Y = 0.25$ GPa. Fig. 9 shows the state of the projectile in these simulations at selected different times (since the impact velocities are very different). One can clearly see the overall resemblance in projectile position for these different

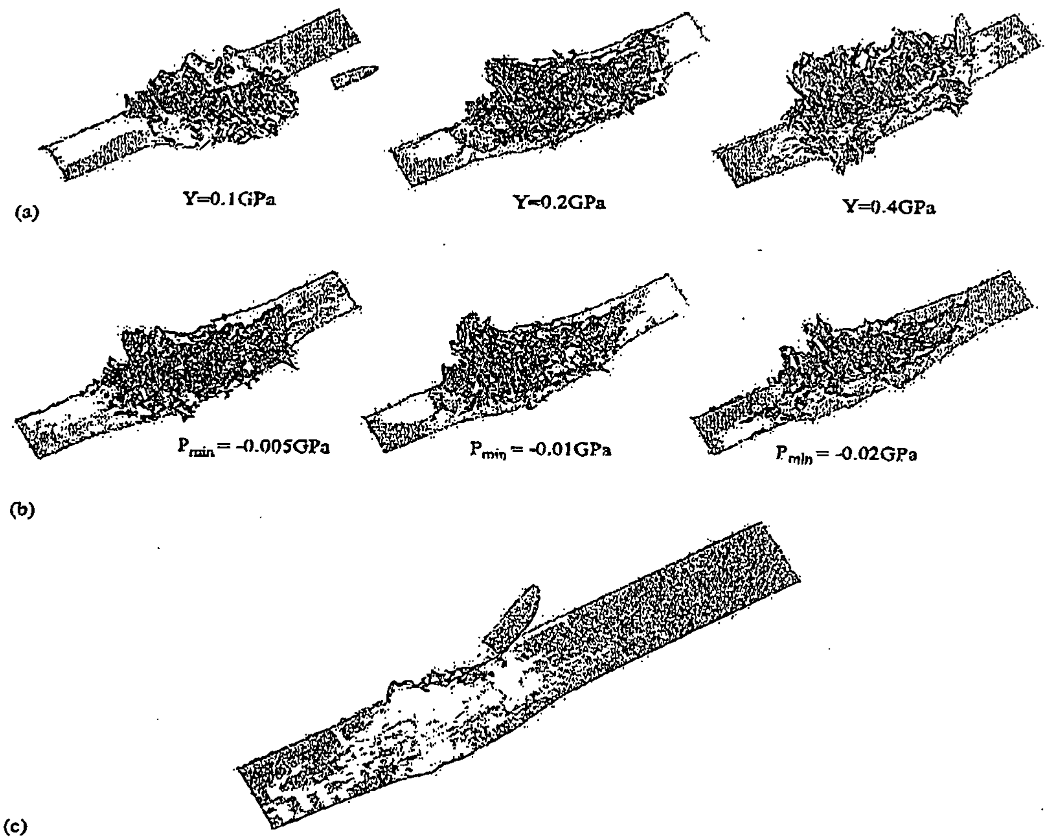


Fig. 6. (a) The influence of Y for constant $P_{min} = -0.01$ GPa (at 200 μs after impact). (b) The influence of P_{min} at constant $Y = 0.2$ GPa (at 160 μs after impact). (c) Increasing target strength to $Y = 1.0$ GPa ($P_{min} = -0.01$ GPa) results in a regular ricochet (at 70 μs after impact).

cases. Thus, the nondimensional parameter, $\rho_p V^2 / Y_t$, is relevant also for the strong effect which we analyzed here.

4. Additional verification

The simulations described above enhance our phenomenological picture for the interaction between the AP projectile and the brittle Plexiglas plate. In particular, we find that target elements at the front face, around the impact point, lose their strength relatively early in the process, exerting a negligible force on the projectile. At the same time, target material below the projectile nose remains intact for a longer time and continues to deflect the projectile. In order to enhance

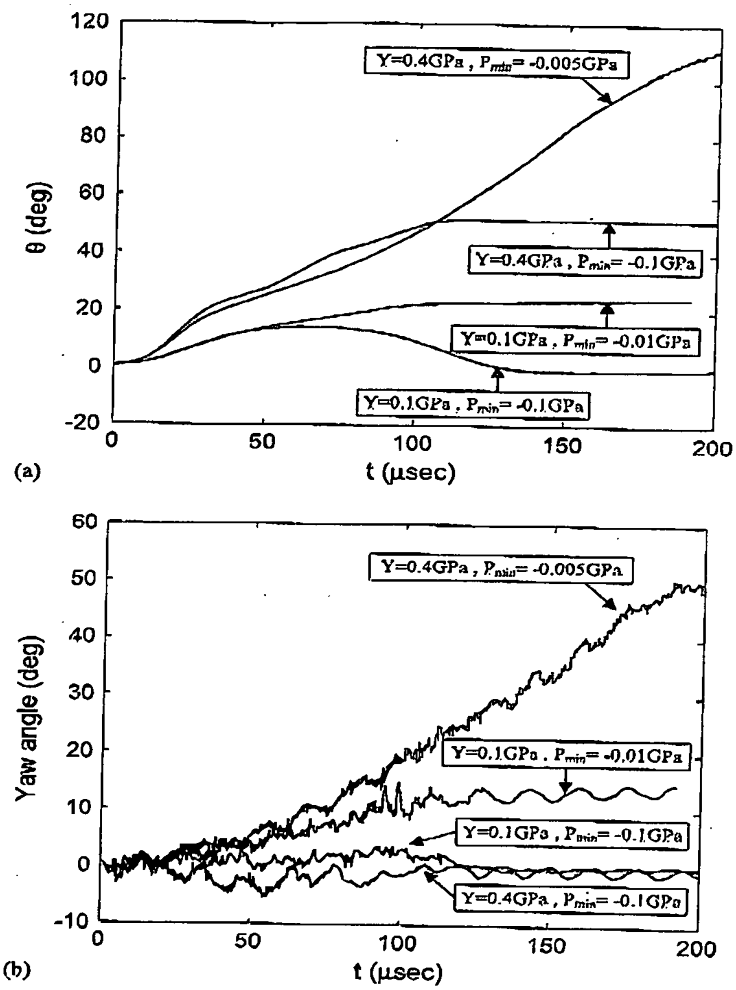


Fig. 7. (a) Time evolution of projectile deflection angle during the penetration of Plexiglas plate in simulation. (b) Time evolution of projectile yaw angle during the penetration of Plexiglas plate in simulation.

this explanation we performed an experiment and a simulation, with a specially designed Plexiglas target, in which the failure of the material around the impact area is reduced. This was achieved by adding another Plexiglas layer (20 mm thick) to the regular 20 mm target. The additional layer had a square section removed from it so that the impact point was at the middle of this 40 mm target, as shown in Fig. 10.

The idea behind this arrangement is to have the same 20 mm target material for the projectile to penetrate (as before), while the impact face above the penetration channel is thickened to 40 mm.

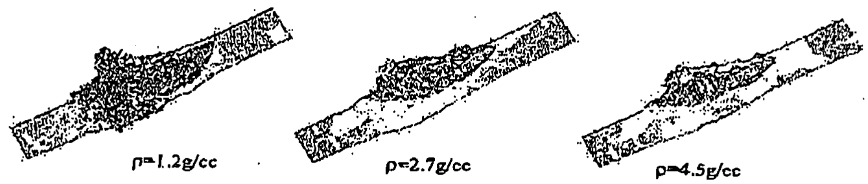


Fig. 8. The influence of target density on projectile deflection (at 130 μs after impact).

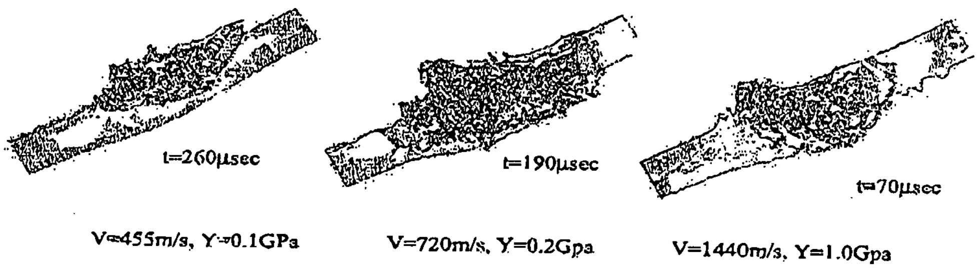


Fig. 9. Simulation results for low and high impact velocities ($P_{min} = -0.01$ GPa).

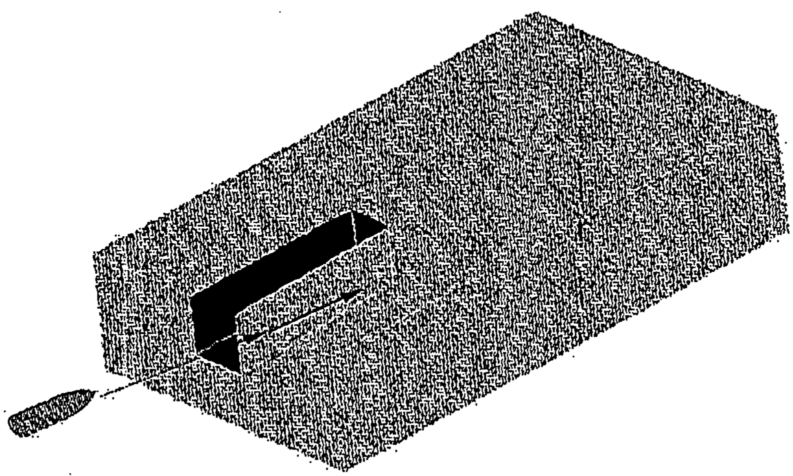


Fig. 10. The composite 40 mm target with the square section removed in the center.

This way we should prevent the early failure of the area above the impact point, reducing the asymmetric forces. This reduction should result in a complete penetration by the projectile, if our phenomenological description is correct.

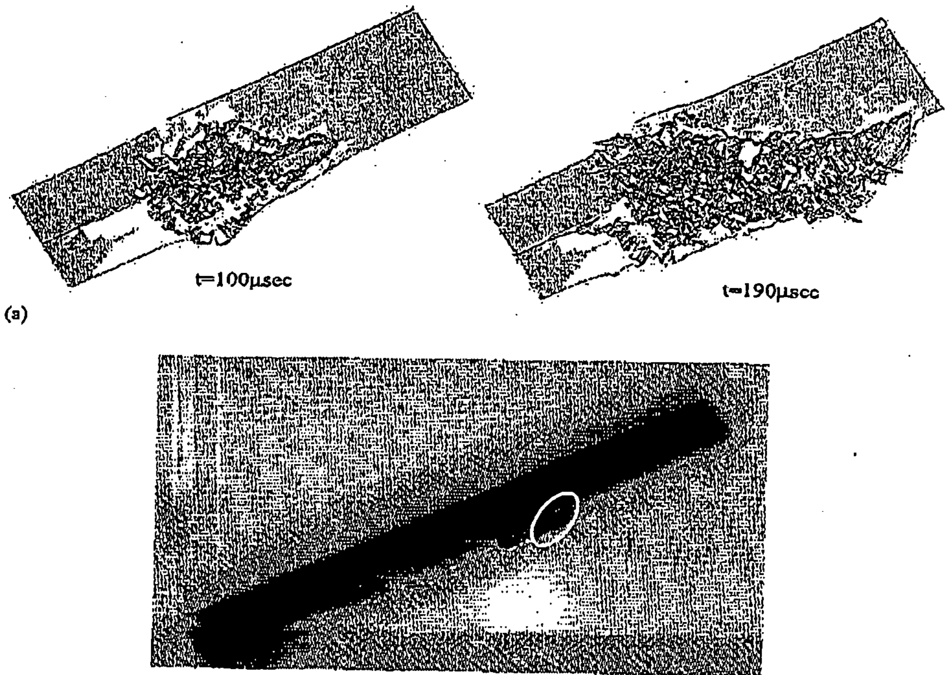


Fig. 11. Simulation and experimental results: (a) simulation for 100 and 190 μs; and (b) flash X-ray at 200 μs.

Fig. 11 shows the results of both simulation and experiment. In both cases the projectile perforated the lower 20 mm of the target, as expected. Moreover, even the orientation of projectile axis is similar in simulation and experiment. Thus, our simple picture for this complicated interaction is strongly enhanced by this combination of experiment and simulation.

5. Conclusions

Inclined Plexiglas and epoxy plates have been found to exert a strong asymmetric force on impacting 0.3″ AP projectiles. This interaction results in a strong deflection and yaw of the projectile, which has not been evidenced by other inclined targets (either metals or polymers). In a series of 3D simulations we showed that the important material properties, which govern this effect, are high brittleness (large compressive strength and low tensile strength) and low density of the plate material. We also demonstrated the similarity of simulation results for different cases with a constant $\rho_p V^2 / Y_t$ ratio, which has been shown to be an important parameter in many terminal ballistics phenomena.

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